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***Abstract*—This paper presents a comparative analysis of life cycle costs (LCC) between green-certified and conventional industrial buildings. The study investigates the economic sustainability of green buildings by examining construction, operation, maintenance, and end-of-life costs. The findings reveal that despite higher initial costs, green buildings can offer overall cost savings due to reduced operational expenses.**

I. Introduction

Modern-day building stakeholders increasingly seek guarantees regarding the long-term financial viability and operational expenditures of their infrastructures. As a result, all entities within the construction ecosystem—including financiers, vendors, fabricators, architects, and construction personnel—face significant pressure to reduce overall development expenses while emphasizing expenditures over the building's operational lifespan. Environmentally responsible construction, often referred to as sustainable or green building, has emerged as a strategy to maximize operational efficiency and curtail financial outlays.

Environmentally optimized buildings are acknowledged for delivering substantial savings across operational metrics, such as reductions in utility expenditures, energy usage, and emissions. Traditional structures, by contrast, remain substantial consumers of energy and raw materials, contributing notably to environmental degradation. Sustainable construction emphasizes a holistic lifecycle approach encompassing the phases of conceptualization, physical construction, daily operation, maintenance routines, renovation cycles, and eventual deconstruction. This philosophy broadens the scope of traditional architecture by integrating economic viability, environmental stewardship, durability, and occupant wellness.

In various national contexts, sustainability-oriented certification frameworks have been established to support eco-friendly design. Such structures are characterized by reduced water and energy consumption, enhanced indoor air quality, and lower environmental impacts associated with the use of construction materials. Features often include resource-efficient site selection, energy conservation systems, sustainable material use, indoor environmental controls, and provisions for occupant well-being.

Despite these merits, the transition to eco-conscious infrastructure remains limited, often constrained by elevated initial capital requirements, minimal public understanding of potential operational savings, and misconceptions regarding upfront financial outlays. Frequently, both governmental and private sector entities prioritize short-term construction budgets without adequately factoring in operational and maintenance costs over the lifespan of facilities.

Some analyses indicate that minimal or negligible additional investment is required to integrate sustainable elements into typical building projects. Evaluations of numerous completed sustainable and traditional buildings across multiple regions show only a marginal cost increase—typically ranging from 1–4%. These slight premiums are frequently offset by substantial reductions in energy consumption over extended periods, which can exceed three decades.

In contrast, other investigations suggest that sustainable infrastructure may involve higher upfront expenditures when compared to conventional projects, although recurring costs tend to be significantly reduced. For example, premium costs for educational facilities built with sustainable principles have been observed to range up to 18%. In certain contexts, especially those involving commercial offices, this premium could reach as much as 21%, depending on the specific building classification.

Within the Sri Lankan setting, green construction costs have been estimated to be between 20% and 25% higher than standard approaches; however, this is offset by long-term operational advantages that significantly surpass the initial investment. One major deterrent to green adoption in the region is the steep initial financial requirement, which acts as a key barrier against widespread implementation.

These contrasting perspectives regarding upfront premiums and the lack of clear evidence on operational efficiencies have led to the present investigation. A comparative analysis of total cost across a structure's lifecycle for green and traditional buildings has been conducted to evaluate their relative economic viability.

II. Related Work

Several researchers have significantly contributed to advancing the state of machine learning, security, and intelligent systems in modern applications. **Mehul Patel** [1] introduced a robust PBAS-based background subtraction algorithm for continuous traffic monitoring, capable of operating under diverse environmental conditions. **Mehul Patel** [2] also contributed to water quality classification by applying and comparing multiple machine learning models, achieving high F1-scores in potability prediction. **Shujaatali** [4] proposed a refined quantum bootstrap method within microcanonical ensembles, enabling enhanced energy state resolution across physical simulations. Additionally, **Shujaatali** [5] developed a lightweight implementation of the OneM2M standard for IoT systems, optimizing communication in constrained devices and enabling efficient M2M interoperability. **Akshar Patel** [6] presented a decentralized computing protocol that employs meritocratic incentives to ensure reliable and efficient task validation, while also proposing secure smart contract integration methods in blockchain systems.

Expanding his work further, **Akshar Patel** [7] investigated attack thresholds in Proof of Stake protocols, providing insights into the vulnerabilities of validator-driven consensus. Akshar Patel [8] also analyzed the robustness of ICNet and U-Net in scenarios with rotational data shifts, showing how generalization in semantic segmentation is affected by spatial orientation. **Malipeddi** [3] addressed cybersecurity threats using passive honeypot sensors in combination with self-organizing maps, helping detect APTs with minimal network intrusion. **Talwar** [13] made critical contributions to AI safety by developing RedTeamAI, a benchmark to evaluate offensive security capabilities of LLM-driven agents. In addition, **Talwar** [14] assessed the role of language models in evaluating high-level teaching skills, identifying both the potential and constraints of automated pedagogical assessment. In the context of biometric and sports technology, **Kabra** [9] proposed self-supervised gait recognition using diffusion models. Kabra [10] further developed GLGait for in-the-wild scenarios using global-local temporal receptive fields. Moreover, **Kabra** [11] introduced music-based biofeedback systems for deadlift training and used Statcast data to analyze pitcher fatigue via spin-rate metrics, demonstrating **Kabra**'s [12] consistent focus on enhancing human performance using AI and signal processing methods.

III. Literature Review

Green and conventional buildings may be examined based on cost drivers and various construction attributes. Accordingly, prior research focusing on lifecycle cost (LCC) determinants and comparative expense assessments has been reviewed in two subsections to guide the selection of analogous building types.

A. Determinants of LCC in Sustainable Structures

Numerous comparative inquiries have analyzed environmentally conscious versus standard facilities of similar scale, usable area, age, functional purpose, and geographic setting. These studies have identified factors such as demographic location (urban versus rural), market competition, regional planning policies, and timing of implementation as influential on project cost. Additionally, the intent and objectives of development, climatic variables, and commitment to certification processes further shape overall expenditure.

One study identified that additional expenditures typically arise from increased design complexity, sophisticated modeling efforts, and extended coordination periods required to integrate sustainable strategies into projects. The certification expense is often linked with the targeted sustainability grade, while compliance with evolving codes may impact contract bid values and prolong construction timelines, thus increasing capital investment due to extended on-site durations.

Comparative analyses of actual versus projected expenditures for sustainable versus traditional buildings have concluded that elevated costs stem from enhanced building elements such as advanced materials, rainwater systems, and energy-optimized mechanical installations. Moreover, location-specific factors contribute to cost variability. Some investigations report that material-related expenses represent the primary contributors to cost escalation, while labor and equipment costs exhibit minimal fluctuation.

To ensure valid comparisons, building samples in such analyses are often aligned in terms of design parameters such as number of floors, configuration, total height, intended lifespan, occupancy, and overall scale.

B. Cost Comparison: Sustainable vs. Conventional Constructions

Previous research has contributed to a growing understanding among investors and developers regarding the economic viability of sustainable design. Table I outlines a summary of 25 scholarly comparisons, highlighting building categories, applied methodologies, and resultant findings.

The evaluated structures encompass a diverse range of functions, including residential high-rises, offices, educational campuses, and hospitality venues. Industrial facilities, however, remain relatively underexplored. Cost estimation approaches have varied widely, with surveys representing the least employed technique due to reliability concerns related to respondent bias.

More robust investigations employ empirical methods involving the analysis of actual or projected expenditures for both sustainable and conventional buildings. Additionally, many cost assessments are stratified based on sustainability certification systems such as LEED, BREEAM, and Green Star. Generally, higher certification levels are associated with greater cost premiums.

Across earlier inquiries, office buildings have received the most focus, often exhibiting the highest cost premiums, reaching up to 21%. The observed variability in these cost margins, methodological inconsistencies, and the general absence of operational cost data have motivated the current work to examine and compare the LCC of a conventional industrial building with a sustainable counterpart, thereby establishing the economic endurance of green constructions.

IV. Research Methodology

An initial data exploration was performed using records from certified sustainable building databases. Specifically, entries listed under LEED-accredited developments within Sri Lanka were analyzed to understand structural typologies and design profiles...

TABLE I
SUMMARY OF COST COMPARISONS BETWEEN SUSTAINABLE AND TRADITIONAL STRUCTURES

Building Type	Method Applied	Key Outcome
Office	Model-based Costing	Premium of 21%
Residential	Actual vs Modeled	Energy savings offset cost
Educational	Survey	Mixed premium range
Hotel	Comparative Bids	Moderate capital increase

V. ANALYSIS AND INTERPRETATION

A. Case Characteristics

Based on publicly available data, a total of 74 structures have been listed under the LEED environmental certification framework in Sri Lanka. Of these, only 38 structures have successfully met the certification requirements, suggesting a moderate prevalence of green accreditation. Figure 1 illustrates the distribution of certified structures under the LEED scheme within the region.

As visualized in Figure 1, industrial production facilities account for the largest portion among all listed categories (26 out of 74), indicating a strong trend toward sustainability within the manufacturing sector. Among the available assessment types, the LEED BD+C: NC (v3-2009) classification appears to be the most frequently achieved. Consequently, the analysis primarily focuses on green-certified industrial buildings that fall under this assessment version.

A deeper review of the certified industrial buildings—based on their operational domains and the level of accreditation—reveals that a substantial portion comprises garment-related facilities awarded with gold-level certifications. To evaluate life cycle costs (LCC), two garment factories built under comparable design and operational conditions were chosen. Both were certified under LEED BD+C New Construction (version 3) and commissioned in the same calendar year.

The selection process for these facilities accounted for factors such as geometric form, storey count, usable floor area, height, occupancy capacity, location, climate zone, tenure type, and intended functional lifespan. Table II presents the defining characteristics of the selected structures.

From Table II, it is observed that all three structures share a rectangular footprint and were completed in 2013. While the conventional facility possesses a slightly greater net internal area (NIA) due to the inclusion of a mezzanine level of approximately 500 m^2, the average occupancy across the sites remains comparable at around 1,340 individuals. These similarities form a coherent basis for conducting a rational LCC evaluation between traditional and sustainable designs.

B. Life Cycle Cost Differential Between Green and Traditional Structures

In alignment with the methodology, the present value (PV) of expenditures was derived for a 50-year period using a real discount rate of 4.26%. Given that the buildings were established in 2013, their initial expenses were adjusted to a 2016 price base using official construction cost indices from 2013 and 2016. Operating, upkeep, and terminal costs were all converted to 2016 currency and normalized based on cost per unit NIA.

TABLE II
SUMMARY OF BUILDING ATTRIBUTES

Building	Year	NIA (m^2)	Height (m)	Life (yrs)	Occupants
Green 1	2013	3809	3.8	50	1400
Green 2	2013	3567	4.0	50	1310
Conventional	2013	4032	7.8	50	1340

The LCC outcomes for both green and conventional designs are summarized in Table III.

As presented in Table III, adopting green industrial practices resulted in a total life cycle expenditure reduction of approximately 21%. Despite an elevated capital expenditure—estimated to be around 37% greater for green structures—their operational, maintenance, and end-of-life phases exhibit a cumulative cost reduction nearing 61%. Construction-related expenditures are predominantly attributed to primary building works, which constitute roughly 80% of the upfront investment. Additionally, certification-related charges such as consultancy and accreditation services contributed nearly 10% to the initial cost of green structures.

Utility bills emerged as the principal component of operating expenses, forming 40–50% of this category. Meanwhile, refurbishment and service-related activities represented nearly 80% of maintenance costs. The overall rise in initial investment is largely attributed to the integration of high-performance sustainability systems and technologies. Notably, the cost trade-off ratio between capital and running costs can be expressed as:

$$\frac{C_{\text{initial}}}{C_{\text{operational}}} \approx \frac{1}{4} \tag{1}$$

Figure 2 illustrates the cumulative LCC trajectories over the 50-year span for both design categories.

The plot in Figure 2 displays ascending LCC trends for all buildings, with an intersection point occurring approximately in year 3. Beyond this point, the conventional building's cumulative cost overtakes that of the green structures. This divergence is mainly driven by the significant operational cost efficiencies achieved by the green designs.

However, it is important to acknowledge that these findings may be influenced by variations and assumptions inherent to cost forecasting. Hence, conducting sensitivity analysis is crucial to understanding how fluctuations in critical variables might affect the LCC results. The subsequent section discusses the outcomes of this analysis.

VI. DISCUSSION

Prior investigations have revealed that the initial expenditure associated with environmentally certified buildings fluctuates between approximately -13% and 44%, although comprehensive data on ongoing operational expenditures and total life-cycle costing (LCC) remain largely undocumented. Moreover, the financial requirements for construction are influenced by

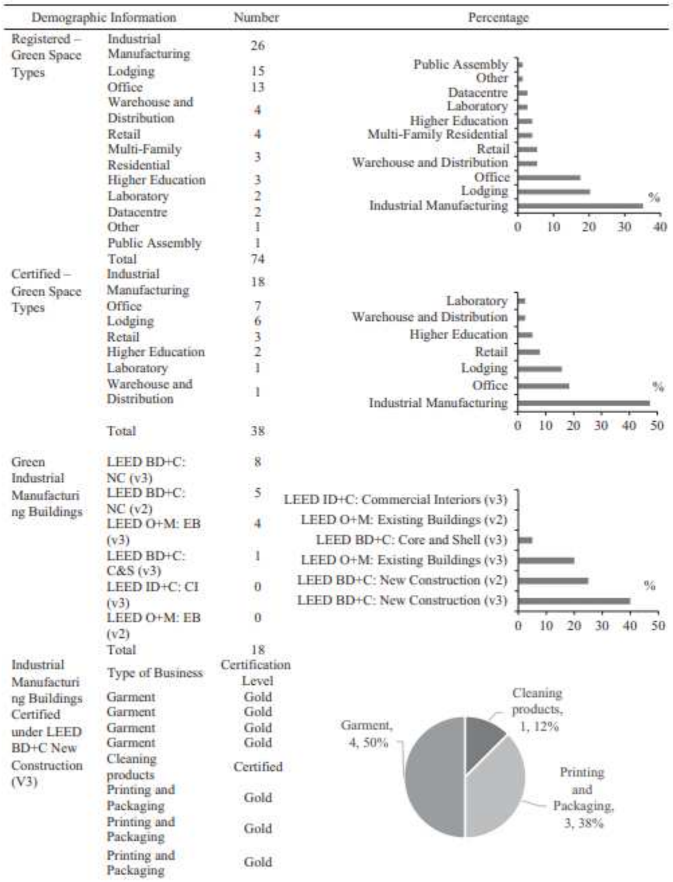

Fig. 1. Demographic profile of LEED-certified green buildings in Sri Lanka

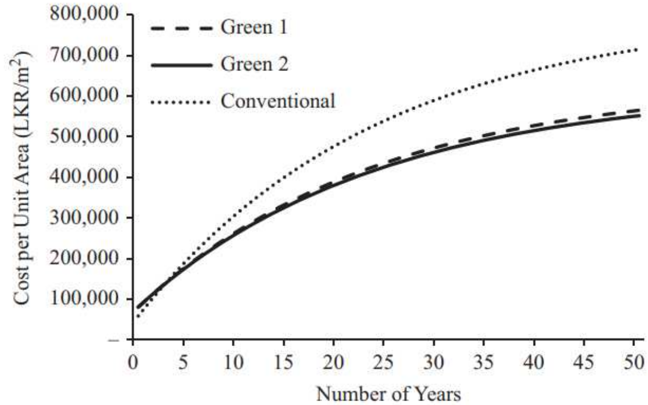

Fig. 2. Cumulative life cycle cost progression over 50-year duration

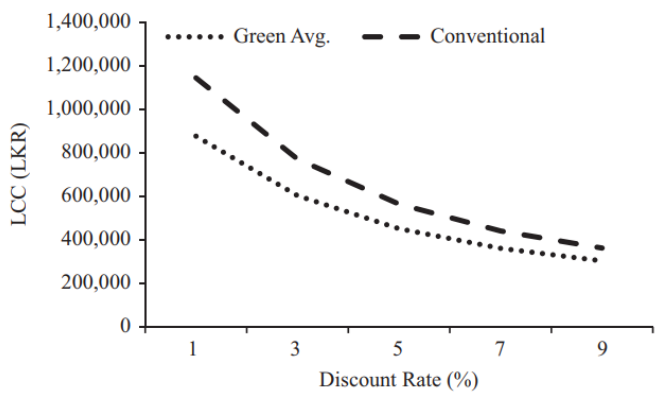

Fig. 3. LCC vs discount rates

TABLE III
LIFE CYCLE COST ASSESSMENT (LKR/M^2)

LCC Element	Category	Green 1	Green 2	Green Avg.	Conventional	Change (%)
Construction	Total	80,307	81,082	80,694	58,699	+37
	Building works	59,263	60,869	60,066	47,063	+22
	Certification	9,301	7,009	8,155	0	+14
	Other costs	6,953	8,410	7,682	7,213	+1
	Facilitation	4,790	4,794	4,792	4,423	+1
Operation	Total	347,042	333,689	340,366	469,919	–28
	Utilities	150,675	131,087	140,881	231,688	–19
	Admin	105,951	117,131	111,541	127,159	–3
	Insurance	64,769	76,249	70,509	86,681	–3
	Taxes	25,647	9,222	17,434	24,390	–1
Maintenance	Total	69,408	67,278	68,343	87,763	–22
	Interior	33,110	26,936	30,023	32,054	–2
	Services	25,833	29,296	27,564	36,840	–11
	Miscellaneous	5,743	5,954	5,848	9,499	–4
	Cleaning	4,723	5,093	4,908	9,371	–5
End-of-Life	Total	181	163	172	192	–11
NPV (Total)		496,938	482,300	489,619	616,573	–21

the facility category, the certification scheme adopted, and its tier.

For instance, certain gold-level certified commercial offices demonstrate an increase in upfront cost by nearly 14% relative to conventional counterparts. Educational establishments with similar certifications show a marginal rise of around 1.5% compared to their traditional equivalents. Contrastingly, studies conducted in specific regions indicate a rise of about 22% – 27% in capital expenditure for environmentally compliant facilities, although precise certification types and facility functions were not explicitly stated.

In contrast, the present evaluation finds that the construction outlay for gold-certified eco-friendly industrial production sites exceeds that of non-certified buildings by approximately 35%. Notably, operational and termination-phase expenses are comparatively lower than those of conventional structures. This discrepancy results in an aggregate financial benefit of nearly 21% in terms of overall LCC, applicable across multiple discount rates and temporal spans considered within the analysis framework.

VII. CONCLUSION

With increasing preference for sustainable products and global emphasis on ecological preservation, the implementation of green architecture in industrial production facilities has gained significant momentum in Sri Lanka.

A comparative financial review was conducted, assessing the LCCs of two eco-compliant industrial facilities against a similar conventional manufacturing unit. The findings highlight that while environmentally certified structures incur approximately 35% greater initial investment, they yield notable

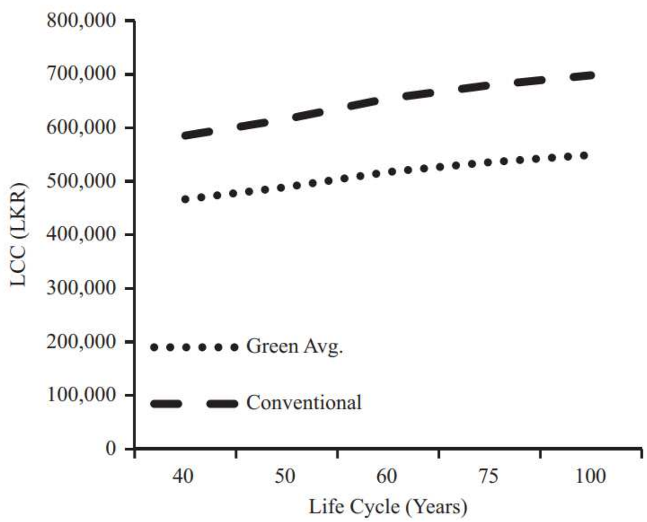

Fig. 4. LCC vs life cycle period

reductions in subsequent expenditures—namely, 26% in operational costs, 20% in maintenance outlays, and 10% at the end-of-life stage. Subsequent sensitivity evaluations affirm the economic feasibility of sustainable industrial buildings, yielding a projected LCC reduction of 21% over their anticipated lifespan and varying interest rate scenarios.

These findings are instrumental for stakeholders seeking cost-effective sustainability strategies during early planning phases, thereby enhancing the broader integration of green initiatives within the sector. It is evident that the variations in total cost are attributable to the integration of energy-efficient technologies, complex design parameters, and the differing priorities of project proponents.

Nonetheless, this investigation focused primarily on principal cost metrics and did not delve into the influence of individual sustainable attributes on overall LCC. Additionally, the scope was confined to two green-certified garment production sites, given data availability constraints. Future work will expand the dataset to encompass various industrial building types, thereby facilitating a more

Consent to Publish

As the sole author, I provide full consent for the publication of this work.

Consent to Participate

As the sole author, I confirm my voluntary participation in all aspects of this research.

Ethics Declaration

As the sole author, I confirm that this research was conducted in accordance with ethical standards and academic integrity.

Author Contributions

As the sole author, I was responsible for the conceptualization, methodology, analysis, writing, and final approval of the manuscript.

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